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THE COLLAPSED FAST FIELD PROGRAM (FFP).(U)
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ABSTRACT

The flexibility of the Fast Field Program (FFP) can be improved considerably with the utilization of a technique for collapsing or folding the kernel of the function to be Fourier transformed. The analysis for the incorporation of this method is given and its usefulness is discussed and demonstrated.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

The prediction of propagation loss at close ranges poses a severe problem for normal mode calculations at both ends of the frequency spectrum. This predicament is related to the number of discrete eigen values included in the normal mode summation, and the exclusion of the contribution from a possible continuous distribution of eigen values.

The range to which the contribution from the continuous spectrum is significant should generally decrease with increasing frequency. The number of discrete eigen values, however, generally increases with increasing frequency and it is found that more of these higher ordered modes are needed in the summation to achieve accuracy at close ranges.

As the frequency decreases the concern is not with calculating enough discrete modes but with the possible contribution from the continuous portion of the eigen value spectrum. At a sufficiently low enough frequency it is possible to be below the cut off frequency, that is no discrete modes are excited, and one is left with only the continuous spectrum. Instances of this type will be the subject of a forthcoming technical note. The present interest is with the case where an insufficient number of discrete modes have been used in the normal mode summation.

Although the Fast Field Program (FFP) is not an eigen value solution, problems can arise when it is utilized for near field calculations. The difficulty lies with a sampled wave number region which does not include a sufficient portion of the smaller wave numbers. This situation is analogous in part to excluding the discrete higher ordered modes in the normal mode summation. FFP calculations will automatically include the contribution from a continuous distribution of eigen values if their general location in the wave number domain is included in the sampling region.

Problems of a different nature occur when it is desired to utilize the FFP with a so called "mini" computer. One such problem is that mini computers usually have a much smaller memory than their large third generation counterparts.

In this note a scheme, uniquely suited to the FFP, is discussed which provides solutions to both of the above mentioned difficulties.

THE COLLAPSED KERNEL

The pressure field for a point monochromatic source is given (Eq. (4) of reference (1)) as

$$\psi(z, r_n) \doteq \Delta\xi \left(\frac{2}{\pi i}\right)^{1/2} \frac{e^{i\xi_0 r_n}}{r_n^{1/2}} \sum_{m=0}^{N-1} E_m e^{i2\pi mn/N} \tag{1}$$

where $E_m = G(z, z_s; \xi_m)\, \xi_m^{1/2} e^{i m r_0 \Delta\xi}$

is the kernel evaluated at the discrete values of the wave number's horizontal component,

$$\xi_m = \xi_0 + m\Delta\xi \qquad m = 0, 1, \cdots N-1$$

The field is given at the discrete ranges

$$r_n = r_0 + n\Delta r \qquad n = 0, 1, \cdots N-1$$

provided that the wave number sampling distance, $\Delta\xi$ and the range resolution, Δr are related according to

$$\Delta\xi\, \Delta r = \frac{2\pi}{N}$$

where N is the size of the discrete Fourier transform.

Before discussing the Collapsed Kernel it would be helpful to emphasize the following points:

(a) The extent of the sampled wave number region is $(N-1)\Delta\xi$.

(b) The range resolution is then fixed at $\Delta\lambda = \frac{2\pi}{N\Delta\xi}$.

(c) The size of the FFT is N.

Following the procedure given by A.. Nuttall in Section 2.5 of reference (2) it will be shown that (1) may be rewritten as

$$\psi(z,\lambda_n) = \Delta\xi\left(\frac{2}{\pi i}\right)^{1/2}\frac{e^{i\xi_0\lambda_n}}{\lambda_n^{1/2}}\sum_{m=0}^{N/p-1}(E_c)_m\, e^{i2\pi mn/(N/p)} \tag{2}$$

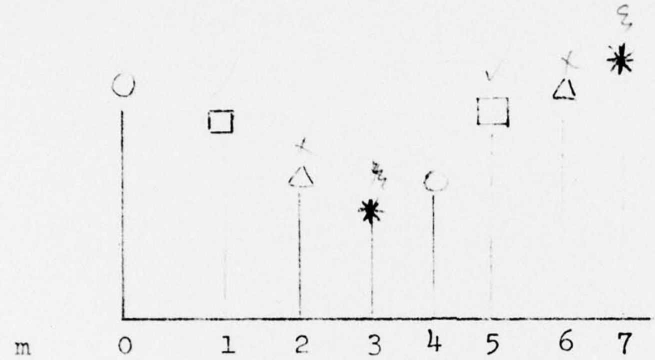
where the Collapsed Kernel $(E_c)_m$ is found to be

$$(E_c)_m = \sum_{k=0}^{p-1} G\left(z,z_s;\xi_0+\left[m+\frac{kN}{p}\right]\Delta\xi\right)\left[\xi_0+\left(m+\frac{kN}{p}\right)\Delta\xi\right]^{1/2} \times e^{i\left(m+\frac{kN}{p}\right)\Delta\xi\lambda_0} \tag{3}$$

In comparing (2) to (1) we find:

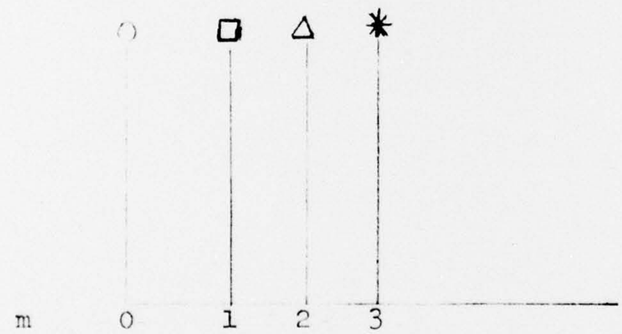
(a) The extent of the sampled wave number region is still $(N-1)\Delta\xi$.

To see this consider the case where N=8 and p=2. Assume that if an 8 point transform were done as in (1) the magnitude of the kernel is given as shown in Sketch 1



Sketch 1

The Collapsed Kernel seen by Eq. (3) is the addition of the magnitudes with the common symbols as shown in Sketch 2.



Sketch 2

(b) The range resolution is increased to $\Delta\lambda = \frac{2\pi}{(N/P)\,\Delta\xi}$

(c) The size of the FFT is reduced to (N/P)

The integral expression for the field is given approximately by

$$\psi(z,\lambda) \simeq \left(\frac{2}{\pi i \lambda}\right)^{1/2} \int_0^T G(z,z_s;\xi)\, \xi^{1/2} e^{i\xi\lambda}\, d\xi$$

It can be shown that beyond some point, T, the magnitude of the kernel will decay exponentially. Then let T be given by $N\Delta\xi$ which determines N since $\Delta\xi$ is fixed from other considerations.

If this interval of integration is subdivided into P segments we have

$$\psi(z,\lambda) = \left(\frac{\rho}{\pi i \lambda}\right)^{1/2} \sum_{k=0}^{P-1} \int_{kT/P}^{(k+1)T/P} G(z,z_s;\xi)\,\xi^{1/2} e^{i\xi\lambda}\,d\xi$$

now let $u = \xi - kT/P$

$$\psi(z,\lambda) = \left(\frac{\rho}{\pi i \lambda}\right)^{1/2} \int_0^{T/P} \left\{ \sum_{k=0}^{P-1} G(z,z_s;u+kT/P)(u+kT/P)^{1/2} e^{+ikT\lambda/P} \right\} \times e^{iu\lambda}\,du$$

If the variables are evaluated at the discrete values

$$u_m = \xi_0 + m\Delta\xi \qquad m = 0,1,\cdots(N/P-1)$$

$$\lambda_n = \lambda_0 + n\Delta\lambda \qquad n = 0,1,\cdots(N/P-1)$$

$$\text{with } \Delta\lambda\,\Delta\xi = 2\pi/(N/P)$$

we have

$$\psi(z,\lambda_n) = \left(\frac{\rho}{\pi i \lambda_n}\right)^{1/2} e^{i\xi_0\lambda_n} \sum_{m=0}^{N/P-1} (F_c)_m\, e^{i2\pi mn/(N/P)}$$

$$(F_c)_m = \sum_{k=0}^{P-1} G\left(z,z_s;\xi_0+\left[m+\tfrac{kN}{P}\right]\Delta\xi\right)\left[\xi_0+\left(m+\tfrac{kN}{P}\right)\Delta\xi\right]^{1/2} e^{i\left(m+\frac{kN}{P}\right)\Delta\xi\lambda_0}$$

AN EXAMPLE

Propagation loss as a function of range at 200 Hz is shown in Figure 1 for a typical summer Mediterranean profile. With the source and receiver placed near the surface, 50 and 100 ft respectively, the FFP shows a well defined image interference pattern out to the first convergence zone. In obtaining these results an N=8192 complex point transform was utilized. The limits of the sampled wave number region were

$$\xi_0 = .208073 \text{ to } \xi_{MAX} = .253578$$

and the distance between samples was

$$\Delta\xi = .555555 \times 10^{-5}.$$

The results are correct everywhere except in the range interval from about two to ten kyds. This error can be traced to the fact that the starting wave number, ξ_0 , is not sufficiently small enough. The problem may be remedied by either increasing N, the number of points in the transform; or by increasing $\Delta\xi$, the distance between samples. The former would require a sustantial increase in computer storage. An increase in the sampling distance could lead to undersampling.

A third alternative would be to utilize the Collapsed Kernel. The Collapsed FFP prediction for this example is shown in Figure 2. A comparison of the two predictions reveals that collapsing has altered the results only in the two to ten kyd range interval with the collapsed values showing the correct continuation of the image interference pattern. This was accomplished by keeping the same ξ_{MAX} and $\Delta\xi$ but sampling the kernel at four times as many points so that the new starting point was

$$\xi_0 = .071540$$

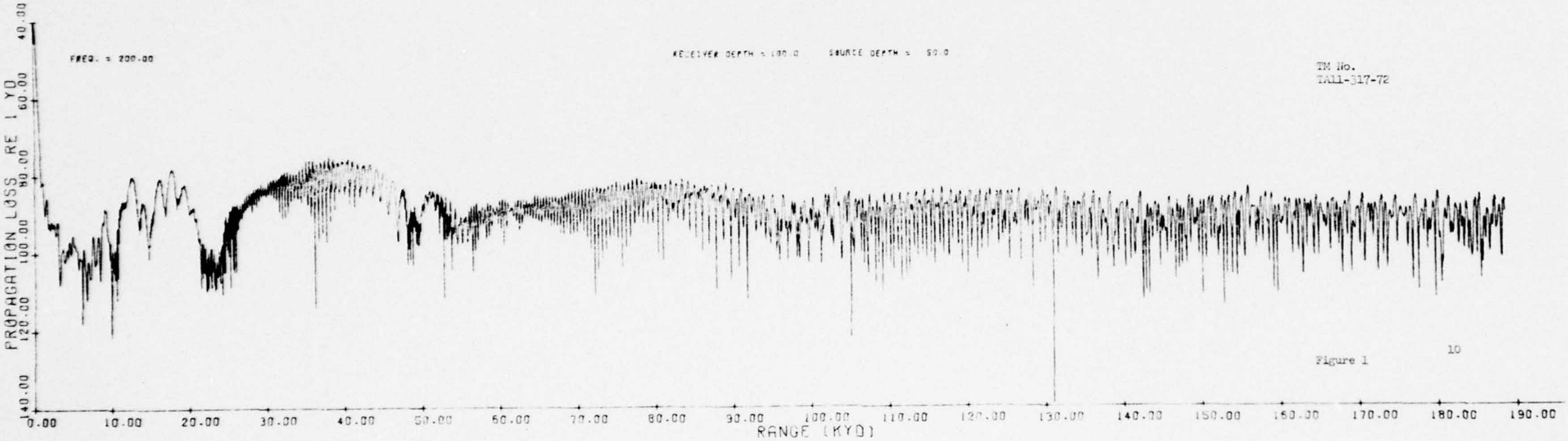
The 32,767 samples were then collapsed four times according to (3) and an 8192 complex point transform was performed. In this instance collapsing has provided the correct answers by increasing the length of the sampled wave number interval without changing the memory requirements or the sampling distance.

Collapsing could also be of value when it is desired to run the FFP on a mini computer. Assume that for some case it is determined that an 8192 point transform is needed in conjunction with some $\Delta\xi$. Also assume that the mini can only handle a 512 point transform. The FFP could be run on the mini by collapsing the kernel sixteen times. The results will be identical to those obtained by doing a straight 8192 point transform except that $\Delta\lambda$ has now been magnified sixteen times.

REFERENCES

1. DiNapoli, F. R., "Fast Field Program for Multilayered Media," NUSC Report No. 4103, 26 August 1971.

2. Nuttall, A. H. "Alternate Forms and Computational Considerations for Numerical Evaluation of Cumulative Probability Distribution Directly from Characteristic Functions," NUSC Report No. 3012, 12 August 1970.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RECEIVER DEPTH = 100.0
SOURCE DEPTH = 50.0
PROPAGATION LOSS RE 1 YD
40.00
60.00
80.00
100.00
120.00
140.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
110.00
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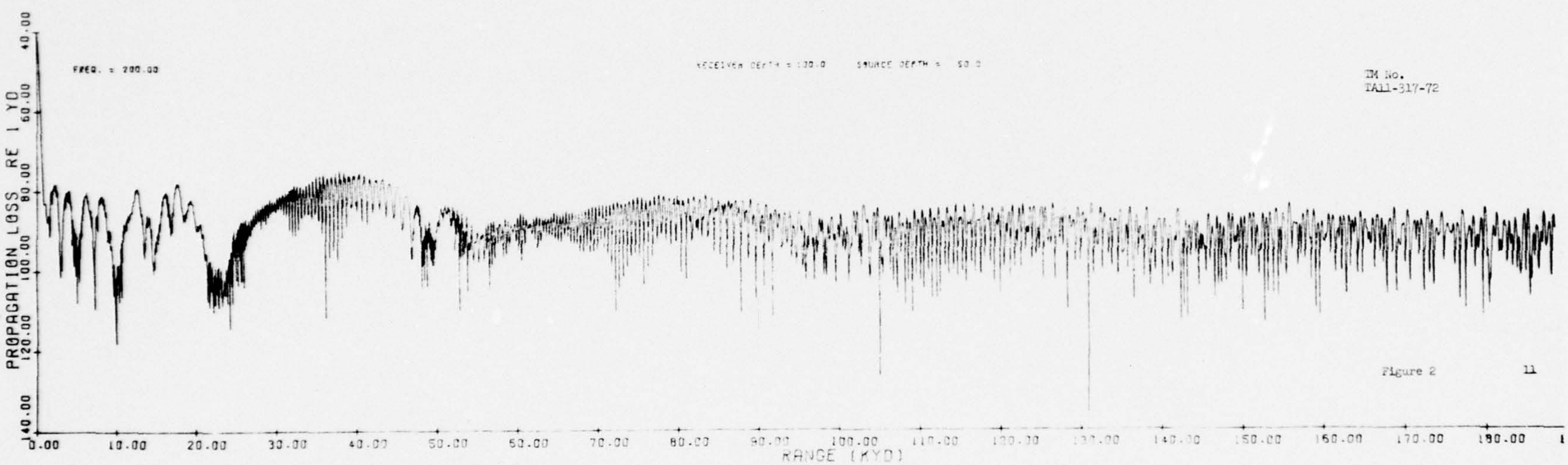
140.00
150.00
160.00
170.00
180.00
190.00
RANGE (KYD)

Figure 1


FREQ. = 200.00
SOURCE DEPTH = 50.0
PROPAGATION LOSS RE 1 YD
40.00
60.00
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100.00
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RANGE (KYD)
0.00
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20.00
30.00
40.00
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70.00
80.00
90.00
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110.00
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Figure 2